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Energy embodiment in Brazilian agriculture: an overview of 23 crops

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ABSTRACT: The amount of energy required to produce a commodity or to supply a service varies from one production system to another and consequently giving rise to differing levels of environmental efficiency. Moreover, since energy prices have been continuously increasing over time, this energy amount may be a factor that has economic worth. Biomass production has a variety of end-products such as food, energy, and fiber; thus, taking into account the similarity in end-product of different crops (e.g.: sunflower, peanuts, or soybean for oil) it is possible to evaluate which crops require less energy per functional unit, such as starch, oil, and protein. This information can be used in decision-making about policies for food safety or bioenergy. In this study, 23 crops were evaluated allowing for a comparison in terms of energy embodied per functional unit. Crops were grouped as follows: starch, oil, horticultural, perennial and fiber, to provide for a deeper analysis of alternatives for the groups, and subsidize further studies comparing conventional and alternative production systems such as organic or genetically modified organisms, in terms of energy. The best energy balance observed was whole sugarcane (juice, bagasse and straw) with a surplus of 268 GJ ha^{-1} yr^{-1}; palm shows the highest energy return on investment with a ratio of approximately 30:1. For carbohydrates and protein production, cassava and soybean, respectively, emerged as the crops offering the greatest energy savings in the production of these functional foods.

Keywords: EROI, starch, oil, fertilizer, fiber, energy balance

Introduction

Since the Industrial Revolution, mankind has become extremely dependent on fossil fuels (Giampietro and Ulgiati, 2005) and after the Green Revolution (1960s) agricultural production also stimulated the demand for energy. Current agricultural practices are heavily dependent on fossil energy and machinery (Cruse et al., 2010; Johansson et al., 2012) that seek to maximize yield, but, most of the time ignore the energy required (Pimentel, 1980). Thus, a detailed understanding of the production system is essential to a proper evaluation of the amount of energy invested in agricultural production (Jordan, 2013).

Material and energy flow assessment are tools which consider not only energy sources, such as electricity or fuels, but also the energy used to produce inputs, such as pesticides, fertilizers, machines and labor required in production processes (Wiedmann, 2009; Johansson et al., 2012; Romanelli et al, 2012a). Energy flow assessment can provide a view of energy performance which shows how it can be improved and estimated by material flow assessment which is an orderly evaluation of the flows and stocks of materials within a defined system (Pimentel and Patzek, 2005; Hall et al., 2009; Romanelli and Milan, 2010a; Romanelli et al., 2012b; Brunner and Rechberger, 2004).

Brazil is an important country where it is possible to open up new areas to agriculture, which will result in an increase in energy consumption in this sector (FAO, 2002; Ferreira Filho et al., 2015). Although the agricultural sector accounts for only 4 % of total energy consumed in Brazil (EPE, 2014), an assessment of energy requirements by Brazilian agriculture is important to an evaluation of its sustainability.

Based on this view, this study aimed to evaluate the energy embodied in 23 crops and assess how much energy is used in their production as well as the energy return, in order to direct subsidies in accordance with an environmental friendly and energy-saving policy that will secure the food supply in Brazil.

Materials and Methods

Energy flows of the following 23 crops were assessed: maize; wheat, cassava, potato, rice, bean, soybean (produced in two Brazilian regions: system 1 in the state of Paraná and system 2 in the state of Mato Grosso), peanut, sunflower, castor bean (comparing two systems, system 1 using low-level technology and system 2 a higher level of machinery and technology; and a third group comprising palm, lettuce, banana, onion, carrot, cucumber, bell pepper, tomato, cotton, eucalyptus, citrus, coffee and sugarcane. For this group, three scenarios of energy output flow (EOF) were developed: the first considering the production of juice only, the second juice plus bagasse, and third juice, bagasse and straw as output.

From the utilisation point of view, there are basically two types of material flow: i) inputs applied directly, such as limestone, fertilizers, seeds and other chemicals used that carry with them amounts of energy for the production process and are currently in use in the fields; and ii) inputs applied indirectly by the use of machinery (including machinery depreciation and effective field capacity) and labor force, which are not physically applied to the crops, but provide services to the operations being performed such as diesel fuel, machinery, and labor.

Material flow determination can then be used as a basis for energy flow assessment by adding up the energy content of all direct and indirect materials used in the production process.

Agricultural inputs applied, time required by mechanized operations, and machinery technical characteristics were obtained from FNP (2012). Castor bean data were obtained from Silva et al. (2010) and soybean data from Romanelli et al. (2012a). Fuel consumption was estimated using the fuel consumption factor tested by Romanelli and Milan (2012b) for tractors and self-propelled machinery (Equation 1). One day was defined as eight hours of human labor.

$$Fc = Cf * TP * TO \quad (1)$$

where: Fc is the Fuel Consumption (L ha^{-1}); Cf the Consumption factor (0.163 L kW^{-1} h^{-1}); TP the engine power of the tractor (kW); and TO the time required per area for one operation (h ha^{-1}).

To calculate the energy required by the production of machinery, the machine mass from commercial folders was used, as well as a factor based on the energy used to produce the machinery, and the useful lifetime obtained from CONAB (2010). It is possible to determine the amount of energy embodied that is applied during the time spent to perform a mechanized operation. The embodiment of depreciated assets, for instance, of machinery, is called machinery depreciation, and in this study it differs from the logic applied when determining economic depreciation (Romanelli and Milan, 2010), which is identified by Equation 2.

$$D = \left(\frac{EEM * Mass}{UL * FC} \right) \quad (2)$$

where: D is the depreciation (MJ ha^{-1}); EEM is the embodied energy of machinery (MJ kg^{-1}); Mass is the machine mass (kg); UL is the machine useful lifetime (h); and FC is the operational field capacity of a specific mechanized operation (ha h^{-1}).

The embodied energy of main inputs assessed and their reference are shown in Table 1.

Energy flows are defined by determining direct and indirect energy inputs, required by an economic system to produce a good or service. Direct energy is the energy used to produce specific goods or services and indirect energy is that already embodied in goods used in process.

Energy input flow (EIF) is the energy used to produce goods or to supply services; and energy output flow (EOF) is the energy generated by the product. The difference between all inputs and the output energy flows is known as the energy balance (EB), given by Equation 3.

Table 1– Embodied energy in the main agricultural production inputs in Brazil.

Input	Unit	Energy index	References
		MJ unit^{-1}	
Diesel	L	35.55	EPE (2014)
Gasoline (air craft)	L	31.95	EPE (2014)
Nitrogen	kg	74.00	Pelizzi (1992)
P_2O_5	kg	12.60	Pelizzi (1992)
K_2O	kg	6.70	Pelizzi (1992)
Limestone	kg	1.70	Pelizzi (1992)
Poultry manure	kg	0.30	Singh and Mittal (1992)
Firewood	kg	12.99	EPE (2014)
Fungicide	L	97.10	Pimentel (1980)
Herbicide	L	454.20	Fluck and Baird (1982)
Insecticide	L	184.70	Pimentel (1980)
Other chemicals	kg	184.70	Pimentel (1980)
Seeds	kg	20.40	Fluck and Baird (1982)
Seedling	unit	0.80	Romanelli and Milan (2010b)
Cassava seeds	m^3	209.50	Calculated by the authors[a]
Labor	h	2.20	Pimentel (1980)
Sugarcane harvester	kg	203.45	Mantoam et al. (2014)
Machinery	kg	68.90	Fluck and Baird (1982)

[a]Estimated using the High Heat Value of cassava (18.95 MJ kg^{-1}) and moisture of 50 %.

Another way to express the relationship between inputted and outputted energy is the energy return on investment (EROI) and the total energy inputted in a good is known as the energy intensity, all of which were determined by Equations 4 and 5, respectively.

$$EB = EOF - EIF \quad (3)$$

$$EROI = \frac{EOF}{EIF} \quad (4)$$

$$EI = \frac{EIF}{Yield} \quad (5)$$

where: EB is energy embodied (MJ ha^{-1}); EOF is energy output flow (MJ ha^{-1}); EIF is energy input flow (MJ ha^{-1}); EROI is energy return on investment (non-dimensional); EI is energy intensity (MJ Mg^{-1}; MJ m^{-3}); Yield (Mg ha^{-1}; m^3 ha^{-1}).

Usually EB and EROI are indicators appropriate to energy crops because both input and output are suitable for evaluation in terms of energy. On the other hand, for food and other non-energy crops, it is convenient to use the EI, which can provide a comparison of energy embodied in a specific material produced from different sources, such as fibers, vitamins, proteins or other components that can serve as the functional unit of a given crop (Franco Junior et al., 2014).

In cases where a crop produces more than one class of functional food, e.g. carbohydrates and proteins in edible beans, it is possible to split the energy embodied into the material produced or allocate the total energy embodied to every product considering that they are co-products of the same process and each one uses the total amount of energy (Odum, 1996). In this study the total energy embodied was used based on a co-products approach.

We considered the functional unit characteristics, one that would have a proper division of energy demand for different materials obtained, that would take into account plant physiology and even consider the organic matter generated by dead roots, for instance. The data provided is a starting point for decision-making, but they must be adjusted by decision makers in cases where crops are grown with more than one functional unit.

Energy output was considered as the caloric value or High Heat Value (HHV) for starch, oil, and sugarcane crops. Crops that do not have energy functions were analyzed by the energy embodied in their products only.

Studies on energy requirements or energy balance generally do not apply statistics. This is due to the uncertainty of some of the energy indices used. For instance, the embodied energy in nitrogen production may be correct for one industry but not for another. To be sure that the index applied is the correct one for the N applied or even to consider the distance traveled from industry (N production) to field (N application), or on the farm, the distance traveled between different plots, one would spend a lot of effort determining the distinct values and they would probably make no difference on the larger scale.

Results and Discussion

Since agriculture needs to provide, among other things, nutritional requirements for the human body carbohydrates, in this context, need less energy to be produced than oils and proteins; that is why crops should be compared within their functional groups. For the sake of comparison crops playing the same nutritional role were grouped by functional product, comprising starch crops, oil crops, and horticultural crops. Cotton and perennial crops were grouped together only for comparison with the others.

Food that is adequate and healthy can be defined as a manner of providing nutrition to a person in the appropriate biological (considering an adequate amount of carbohydrates, proteins, vitamins, and other functional nutrients) and sociocultural (respecting traditional characteristics of regional diet and the mode of preparation) manner, and also provide this food in a the context of a sustainable environment. From this point of view, energy saving crop production is a sustainable way of producing food that is adequate and healthy food.

We summarized the input energy showing direct and indirect energy embodied in the crops studied (Tables 2 to 5).

The average of energy embodied per area was 26.36 GJ ha^{-1}. Certain horticultural crops presented the greatest energy demand per area: potato, onion, and carrot (81.47, 66.24 and 60.00 GJ ha^{-1} respectively), the lowest energy input per area were found in castor bean (system 1), palm and soybean (system 2) with 2.93, 6.28 and 7.32 GJ ha^{-1}, respectively.

Considering energy used according to the EI, the average was 2.41 GJ unit^{-1}. Crops which required the largest amounts of energy were castor bean (system 2), bean and cotton (6.56, 6.25 and 6.06 GJ Mg^{-1} of product). On the other hand, coffee, eucalyptus, and palm were the crops with the lowest amount of energy embodied per unit of product, 27.03 MJ Mg^{-1}, 124.61 MJ m^{-3}, and 314.08 MJ Mg^{-1} respectively .

Broadly, regarding indirect inputs, diesel presented the highest numbers in absolute (GJ ha^{-1}) and relative (%), values of energy input with diesel use values ranging between 8 to 56 % of total energy embodied, with an average value of 25 %. Low percentages are due main-

Table 2 – Direct and indirect energy embodied for starch crops in Brazil.

Culture	Maize		Cassava		Potato		Rice		Wheat		Bean	
	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%
Indirect inputs	2.34	15	4.82	44	8.53	10	7.27	44	2.40	18	3.33	18
Diesel	2.05	13	3.24	29	7.03	9	6.02	36	1.93	14	2.67	14
Machinery	0.29	2	0.61	6	1.31	2	1.15	7	0.46	3	0.55	3
Labor	< 0.01	0	0.97	0.09	0.18	0	0.10	0	< 0.01	0	0.11	1
Electricity	-	-	-	-	5.30	7	-	-	-	-	-	-
Direct inputs	13.15	85	6.21	56	67.65	83	9.27	56	11.09	82	15.41	82
Fertilizers	8.75	56	4.96	45	16.09	20	5.29	32	4.70	35	9.38	50
Seeds	0.41	3	1.05	9	26.52	33	3.06	18	2.98	22	1.12	6
Chemicals	3.99	26	0.21	2	25.04	31	0.93	6	3.41	25	4.91	26
Total (GJ ha^{-1})	15.49		11.03		81.47		16.54		13.49		18.74	
Yield (Mg ha^{-1})	8.80		22.00		30.00		7.00		2.70		3.00	
Carbohydrate content (%)	62		34		16		64		64		61	
	Product											
Embodied energy (MJ Mg^{-1})	1,760.15		501.38		2,715.65		2,363.26		4,994.77		6,247.84	
	Carbohydrate											
	2,838.95		1,474.64		16,972.79		3,692.60		8,762.76		10,208.89	

Table 3 – Direct and indirect energy embodied for oil crops in Brazil.

Culture	Castor bean[a]				Peanut		Sunflower		Palm		Soybean[b]			
	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%
	System 1		System 2								Paraná		Mato Grosso	
Indirect inputs	1.15	39	5.74	58	3.82	40	1.68	20	1.14	18	1.95	25	1.89	26
Diesel	0.69	24	5.21	53	3.31	35	1.57	19	0.71	11	1.59	21	1.52	21
Machinery	0.16	5	0.34	3	0.48	5	0.09	1	0.03	0	0.35	5	0.36	5
Labor	0.31	11	0.19	2	0.02	0	0.02	0	0.40	6	0.01	0	0.01	0
Electricity	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Direct inputs	1.78	61	4.11	42	5.64	60	6.70	80	5.14	82	5.76	75	5.43	74
Fertilizers	1.67	57	3.90	40	2.74	29	5.31	63	3.48	55	0.93	12	1.24	17
Seeds	0.10	3	0.20	2	1.37	15	0.06	1	0.03	1	1.33	17	1.22	17
Chemicals	0.00	0	0.01	0	1.53	16	1.33	16	1.63	26	3.51	46	2.97	41
Total (GJ ha^{-1})	2.93		9.84		9.45		8.38		6.28		7.71		7.32	
Yield (Mg ha^{-1})	0.85		1.50		20.00		4.25		2.20		3.24		3.18	
Oil content (%)	45		45		52		37		20		20		20	
Embodied energy (MJ Mg^{-1})	Product													
	3,451.47		6,563.22		2,223.85		3,810.28		314.08		2,753.66		2,614.67	
	Oil													
	7,669.93		14,584.93		4,246.41		10,298.06		1,570.42		13,768.32		13,073.34	

[a]Source: Silva et al. (2010); [b]Source: Romanelli et al. (2012a).

Table 4 – Direct and indirect energy embodied for horticultural crops in Brazil.

Culture	Lettuce		Banana		Onion		Carrot		Cucumber		Bell pepper		Tomato	
	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%
Indirect inputs	10.26	36	4.88	12	20.90	32	28.94	48	14.59	45	13.63	31	13.04	32
Diesel	6.93	25	3.53	8	15.66	24	23.05	38	10.11	31	9.83	22	9.01	22
Machinery	2.67	9	0.40	1	3.23	5	5.18	9	2.11	7	1.33	3	2.40	6
Labor	0.66	2	0.95	2	2.01	3	0.72	1	2.36	7	2.47	6	1.63	4
Electricity	-	0	-	0	0.74	1	0.36	1	-	0	-	0	-	0
Direct inputs	17.93	64	37.42	88	44.60	67	30.70	51	17.90	55	30.15	69	27.31	68
Fertilizers	17.77	63	33.25	79	41.34	62	29.65	49	16.57	51	26.63	61	23.33	58
Seeds	0.16	1	0.01	0	0.04	0	0.07	0	0.01	0	0.31	1	0.77	2
Chemicals	1.86	6	4.17	10	3.22	5	0.98	2	1.33	4	3.22	7	3.22	8
Total (GJ ha^{-1})	28.19		42.30		66.24		60.00		32.49		43.78		40.36	
Yield (Mg ha^{-1})	22.40		40.00		44.00		42.20		44.00		35.00		85.00	
Embodied energy (MJ Mg^{-1})	1,258.65		1,057.54		1,505.44		1,421.83		738.42		1,250.87		474.81	

ly to massive use of inputs like fertilizers. Eucalyptus plantations reached 20.4 GJ ha^{-1} from diesel use only (56 % of total energy inputted in this crop), carrot and onion also have a high value of energy inputted (23.05 and 15.66 GJ ha^{-1} respectively) relative to castor bean with high technology that has 53 % of its energy inputted from diesel used while having a small amount of energy, 5.21 GJ ha^{-1}.

In terms of machinery, carrot, onion, lettuce, and tomato showed the highest values in GJ ha^{-1} (5.18, 3.23, 2.67 and 2.40 respectively) and in percentage lettuce and carrot (9 %); and cucumber and rice (7 %) showed the highest contributions.

The highest labor contribution reading was bell pepper with 2.47 GJ ha^{-1}, cucumber (2.36 GJ ha^{-1}), onion (2.01 GJ ha^{-1}), and tomato (1.63 GJ ha^{-1}). In relative values, castor bean grown in a low technology system that uses almost no machinery was the highest (11 %); cucumber (7 %), bell pepper and palm (both 6 %). All other crops have values below 5 %, with values close to zero in highly mechanized production systems such as maize, wheat, and soybean.

Based on these results, we can infer that in more intensive agricultural production systems it is possible to disregard labor in energy terms as it represents very low values compared to fertilizers, machines, and diesel without compromising the accuracy of the results.

For direct inputs, out of 17 crop fertilizers the highest energy input recording very high values per area were onion (41.34 GJ ha^{-1}), coffee (39.34 GJ ha^{-1}) and banana (33.25 GJ ha^{-1}). In this context nitrogen accounts for the majority of fertilizer energy inputted, representing 74 %, 77 %, and 93 % of total fertilizer energy for onion, banana and coffee, respectively. Soybean had the lowest value where there was no use of nitrogen as fertilizer.

Table 5 – Direct and indirect energy embodied for cotton and perennials in Brazil.

Culture	Cotton		Eucalyptus		Citrus		Coffee		Sugarcane	
	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%
Indirect inputs	5.13	21	22.80	63	16.98	45	9.83	18	5.39	51
Diesel	4.43	18	20.40	56	14.76	39	8.12	15	4.72	42
Machinery	0.61	2	1.90	5	2.13	6	1.63	3	0.96	8
Labor	0.08	0	0.50	1	0.09	0	0.08	0	0.07	1
Electricity	-	0	-	0	-	0	-	0	-	0
Direct inputs	19.40	44	13.40	37	21.10	55	45.95	82	5.56	49
Fertilizers	13.62	56	10.00	28	9.34	25	39.34	71	4.12	36
Seeds	0.27	1	0.70	2	11.74	31	0.23	0	0.08	1
Chemicals	5.51	22	2.70	7	0.02	0	6.37	11	1.36	12
Total (GJ ha^{-1})	24.53		36.20		38.09		55.78		11.30	
Yield unit	Mg ha^{-1}		m^3 ha^{-1}		Mg ha^{-1}					
Yield	4.05		290.50		34.00		2.064		78.00	
Embodied energy	MJ Mg^{-1}		MJ m^{-3}		MJ Mg^{-1} yr^{-1}					
	6,056.03		124.61		1,121.47		27.03		322.51	

For starch crops, potato has the highest values in total energy applied per area and per mass of starch produced, while bean showed the highest value per mass of crop produced. However, beans have a high content of protein (20 %) which is also important to the human diet so its importance as food must also include this characteristic (Table 2).

For oil crops (Table 3), castor bean grown in a low production technology system showed the lowest value for energy per area, but it also has a small yield with energy embodied per production and per oil higher than others (Silva et al., 2010). Palm oil showed the lowest value of energy embodied per mass of product and oil because it has the highest production per area. Soybean showed high energy embodied mostly because the chemicals applied represent on average, 44 % of total energy inputted into this crop (Romanelli et al., 2012a).

Horticultural crops are characterized by an intense use of tillage and fertilizers, and, consequently, for the highest energy inputted per area, featured onion and carrot crops. These crops have, in many cases, a high harvested product yield, having an energy embodied per product reading that was not so high. When its function as nutritional food is considered (e.g. beta-carotene from carrots and lycopene from tomatoes), they have a high amount of energy per gram of these vitamins (Table 4).

Cotton and each perennial crop were analyzed separately according to their specific characteristics. Coffee has a high energy embodied reading mainly because of the high amount of nitrogen used every year, having 71 % of its total energy embodied from fertilizers. Similarly, cotton has 56 % of its energy embodied from fertilizers and also the highest amount of chemicals, accounting for 22 % of total energy embodied. On the other hand, crops that require many or heavy mechanical operations like citrus, sugarcane and eucalyptus have a high amount of indirect energy embodied from diesel use. All data are shown in Table 5.

Table 6 – Average energy consumed per area in Brazil.

	Starch crops		Oil crops		Horticultural crops		Perennial crops	
	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%
Indirect inputs	4.78	25	2.48	32	15.18	33	12.70	41
Diesel	3.83	19	2.09	26	11.16	24	10.95	36
Machinery	0.73	4	0.26	4	2.47	6	1.50	5
Labor	0.23	2	0.14	3	1.54	4	0.26	1
Electricity	0.88	3	-	-	0.16	0	0.05	0
Direct inputs	20.46	74	4.94	68	29.70	66	20.97	59
Fertilizers	8.19	40	2.75	39	26.93	60	15.23	41
Seeds	5.86	15	0.62	8	0.19	0	2.98	8
Chemicals	6.41	19	1.57	21	2.57	6	2.76	9
Total (GJ ha^{-1})	51.37		14.84		89.91		67.39	

Average values of crops by function group are shown in Table 6 (except cotton which does not fit in any group). The results demonstrate that indirect inputs are no higher than 41 % (perennial crops), with diesel as the highest contributor to energy embodied. Direct inputs are responsible for the majority of energy embodied, around 67 %, with fertilizers being the main source of this, accounting for 60 % on average, of horticultural energy embodied. Despite the collation of all crop groups in Table 6, a simple comparison between energy embodied per area cannot be made because of their different functions.

Nitrogen as one of the nutrients with the highest energy embodied (74 MJ kg^{-1}) as well as its widespread use in many crops contributes especially to direct input, and it can also contaminate groundwater and must be used with parsimony in places close to bodies of water. In Table 7, the values for nitrogen used by area and per mass of crop produced are shown.

Using high amounts of ammonium nitrate, coffee showed the highest value per area and per mass produced. On the other hand, owing to its symbiotic relationship with *Rhizobium* sp. bacteria, soybean has no use of nitrogen.

Table 7 – Nitrogen required per area and per produced mass in the evaluated crops by Brazilian region.

Crop	Region	Total N	Embodied N
		kg ha^{-1}	kg Mg^{-1}
Maize	Paraná	87.60	9.95
Cassava	Santa Catarina	48.00	2.18
Potato	São Paulo	191.88	6.40
Rice	Santa Catarina	61.00	8.71
Wheat	Paraná	50.50	18.70
Bean	São Paulo	97.90	32.63
Sugarcane	São Paulo	86.00	1.10
Castor bean	Bahia	16.40[a]	19.29[a]
		20.40[b]	13.60[b]
Palm	Pará	27.98	1.40
Peanut	São Paulo	4.50	1.06
Sunflower	Goiás	57.90	26.32
Soybean	Paraná	0.00	0.00
	Mato Grosso	0.00	0.00
Lettuce	São Paulo	210.00	9.38
Banana	São Paulo	450.00	11.25
Onion	São Paulo	109.20	2.48
Carrot	Goiás	160.00	3.79
Cucumber	São Paulo	58.00	1.32
Bell pepper	São Paulo	150.00	4.29
Tomato	São Paulo	160.00	1.88
Coffee	São Paulo	456.00	220.93
Eucalyptus	Minas Gerais	71.60	0.25
Citrus	São Paulo	139.50	4.10
Cotton	Mato Grosso	133.20	32.89

[a]System 1. [b]System 2.

EB analysis revealed sugar cane (juice, bagasse, and straw), palm, cassava and sugarcane (juice only) to be the five best results, while potato and both castor bean production systems gave the lowest EB obtained.

It is worth noting that not even the best EB crop, palm production, obtained the highest EROI which reached 30 times more energy available than that used to produce it, which is more than 2.3 times higher than cassava, the second crop with an EROI of 13. Sugar cane (juice, bagasse, and straw), maize and sugarcane (juice and bagasse) complete the group of the five best EROIs obtained. Potato presented the lowest EROI and despite its high energy content, its production required too much energy reducing both EB and EROI (Table 8).

Certain objectives and initiatives for food security discuss sustainable ways to produce food that are environmentally friendly and provide adequate and healthy food. Using the territorial approach as a strategy to promote the integration of public policies and optimization of resources aimed at food production and sustainable rural development can provide an argument for subsidies for technical assistance and extension services.

Furthermore, it can affect strategies for product labeling and increasing income, by developing projects aimed at conservation and sustainable use of biodiversity, showing that many studies on sustainability are necessary to cover all the aspects, including in this study, an approach to energy.

Table 8 – Energy performance of the evaluated crops.

Crop	Energy Balance	EROI[a]	Reference for output energy
	GJ ha^{-1}	%	
Palm	179	30	Bodner-Montville et al. (2006)
Cassava	128	13	Bodner-Montville et al. (2006)
Sugarcane (Juice+bagasse+straw)	268	11	Considering 14 % of trash and Low Heat Value (LHV) of 6.3 MJ kg^{-1} [b]
Maize	119	9	Bodner-Montville et al. (2006)
Sugarcane (Juice+bagasse)	199	8	Considering 13 % of bagasse and LHV of 7.5 MJ kg^{-1} [b]
Soybean (system 1)	53	7	Bodner-Montville et al. (2006)
Soybean (system 2)	52	7	Bodner-Montville et al. (2006)
Rice	90	6	Bodner-Montville et al. (2006)
Peanut	87	6	Bodner-Montville et al. (2006)
Sunflower	44	6	Bodner-Montville et al. (2006)
Sugarcane (Juice)	126	5	NEPA (2004)
Wheat	25	3	Bodner-Montville et al. (2006)
Castor bean (system 1)	7	3	Bodner-Montville et al. (2006)
Bean	23	2	NEPA (2004)
Castor bean (system 2)	7	2	Bodner-Montville et al. (2006)
Potato	15	1	Bodner-Montville et al. (2006)

[a]EROI = energy return on investment, [b]source: Bizzo et al. (2014).

Therefore, we would like to suggest the undertaking of further studies to compare the actual state of production management with alternative models (e.g. agroecological or genetically modified organism), to evaluate if it requires more or less energy than the customary way of producing it.

Conclusion

A wide range of crops important to Brazil was analyzed and described here, giving an outlook of the Brazilian scenario of energy consumption to grow commodities and crops used in the domestic market.

As for starch and oil crops it is possible to compare how much energy is embodied in the many ways to produce them and then use this information as well as other types of data such as economic and cultural approaches to decide which one is best for production depending on its goal.

In terms of the lowest cost to produce carbohydrates as a source of energy, cassava shows the best result. For protein production, soybean is the lowest cost energy crop.

Taking into consideration the amount of carbohydrates and proteins only (and not their functionality) cassava and soybean for human consumption could be promoted in areas where there is this kind of nutritional demand, and consider energy-savings as a reference for decision making.

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